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(54) **MOISTURE-FREE SOG PROCESS**

FEUCHTIGKEITSFREIES SOG-VERFAHREN

PROCEDE DE DEPOT DE VERRE A SEC ET PAR ROTATION

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(73) Proprietor: **MITEL CORPORATION**
Kanata Ontario K2K 1X3 (CA)

(72) Inventor: **OUELLET, Luc**
Granby, Quebec J2J 1M7 (CA)

(74) Representative: **Copp, David Christopher**
Dummett Copp & Co.
25 The Square
Martlesham Heath
Ipswich Suffolk IP5 7SL (GB)

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WO-A-87/06725

- **Journal of the Electrochemical Society**, vol. 135, no. 5, May 1988, (Manchester, NH, US), P.E. Riley et al.: "Characterization of a spin-applied dielectric for use in multilevel metallization", pages 1207-1210
- **J. Electrochem. Soc.**, vol. 137, nop. 1, January 1990, The Electrochemical Society, Inc., G. Smolinsky et al.: "Material properties of spin-on silicon oxide (SOX) for fully recessed NMOS field isolation", pages 229-234
- **1987 Proceedings Fourth International IEEE BLSI Multilevel Interconnection Conference**, Santa Clara, CA, US, 15-16 June 1987, IEEE, C. Chiang et al.: "Defects study on spin on glass planarization technology", pages 404-412

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Description

This invention relates generally to a process for applying spin-glass to a substrate, and more particularly to a process for the planarization of semiconductor wafers. The invention concerns inorganic spin-on glasses.

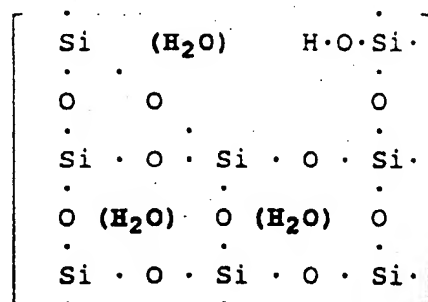
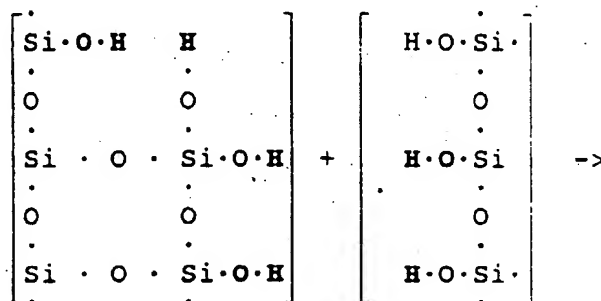
Spin-on glasses (SOG) are proprietary liquid solutions containing siloxane or silicate based monomers diluted in various kinds of solvents or alcohols. They are commonly used for the planarization of semiconductor wafers, i. e. the filling and levelling of the trenches formed between interconnect paths deposited on the wafer. On coating and curing of spin-on glasses, monomers are polymerized by condensation and release of water, solvent, and alcohol. The condensed material is a thin solid film having mechanical, chemical and electrical properties which depend on the starting solution, and the coating and curing process.

There are more than one hundred different SOG solutions currently available. These are classified into two major families:

1) Inorganic silicates.

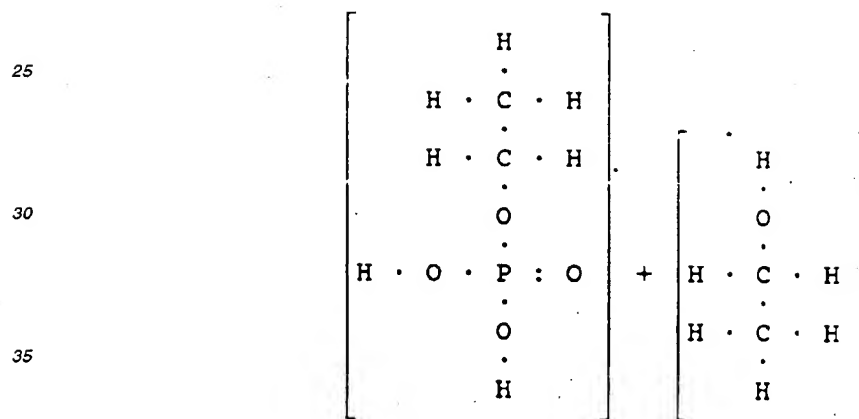
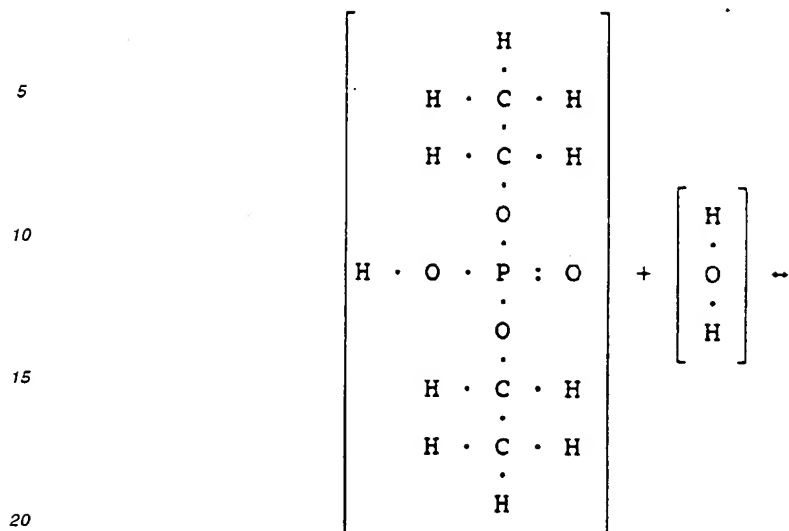
2) Quasi inorganic siloxanes (methyl-, ethyl-, phenyl-, butyl-siloxanes).

The various components of a SOG solution (silicon containing oligomer, solvents mixture, and residual water) are in equilibrium in the liquid phase. Immediately after coating, volatile products (solvents and water) evaporate, and polymerization occurs due to the formation by condensation of silanol, Si-OH, bonds. These produce more water according to the following reaction:



Polymerization continues until the distance between neighbouring silanol groups, Si-OH, becomes too large or when too much by-product, such as water, blocks the condensation reaction. Heating is then required to permit further densification.

Both families of SOG solutions can incorporate boron or phosphorus organometallic catalyst to improve the properties of the films, such as: higher density, reduced hydrogen content, higher coefficient of thermal expansion, better flexibility and higher resistance to cracking. In the SOG solution, the boron or phosphorus organometallic molecules are generally not well bonded to the silicon-containing compounds. Strong bonding generally occurs in the solid state when the film is exposed to relatively high temperatures. These organometallic molecules can nevertheless polymerize in the solution to form poorly bonded polymers that dissociate and form stable polymers during coating and condensation of the film. As an example, a Japanese SOG solution is alloyed with a phosphorus organometallic molecule, $\text{P}_w\text{O}_x(\text{OH})_y(\text{OC}_2\text{H}_5)_z$, which is in dynamic equilibrium with the solutions water and ethanol, $\text{C}_2\text{H}_5\text{OH}$:

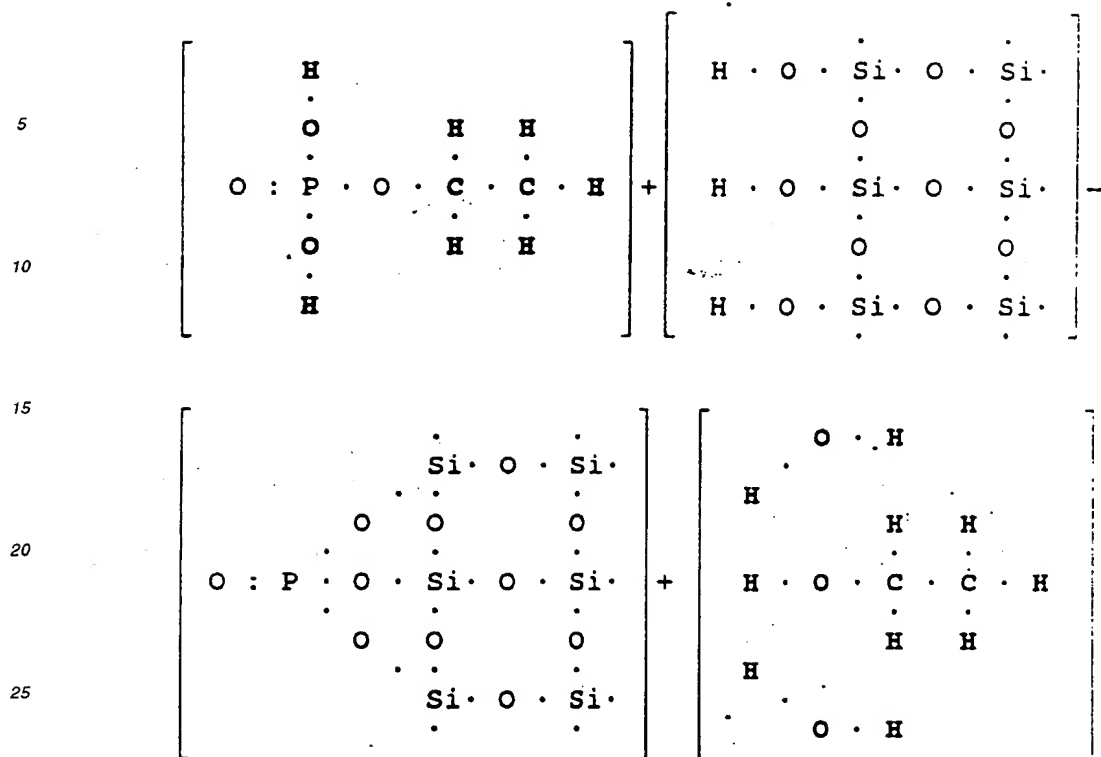


40 If the ethanol $\text{C}_2\text{H}_5\text{OH}$, or water concentration suddenly drops, as during coating and solvent evaporation, the equilibrium is broken and, at high temperatures, the phosphorus organometallic molecule will polymerize and connect to the forming SiO_xH_y film by producing more water and ethanol, $\text{C}_2\text{H}_5\text{OH}$:

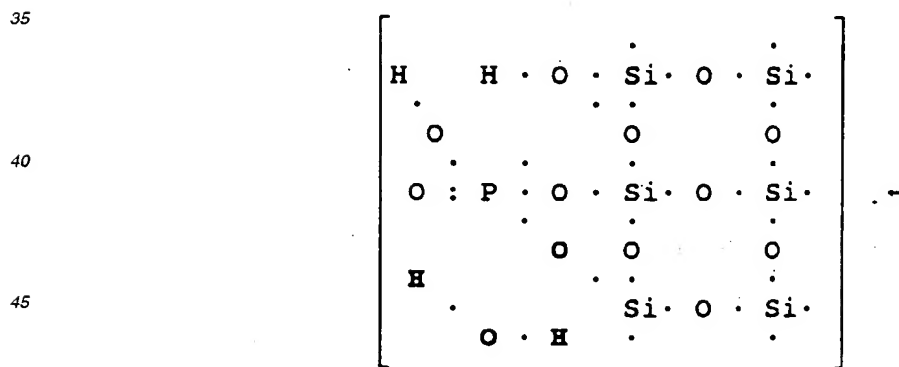
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30 In theory, the phosphorus atom connects to the SiO_2 network with three P-O-Si bonds. These bonds are formed by the condensation of -P-OH or -P-OC₂H₅, and -Si-OH. Water and ethanol are formed as by-products and water must be eliminated quickly to prevent reverse hydrolysis.



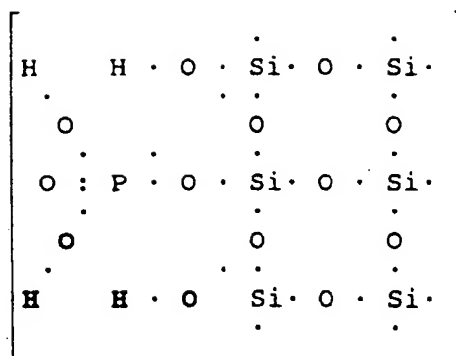
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This reverse hydrolysis is extremely undesirable because it contributes to the incorporation of hydrogen and inhibits the action of the phosphorus organometallic catalyst.

Residual hydrogen forms silanol groups, SiOH. It is very difficult to remove and causes serious yield and reliability problems. If this reverse hydrolysis continues, it is possible to totally disconnect the phosphorus by forming many different acids: hypophosphorus acid, H_3PO_2 ; meta-phosphorus acid, HPO_2 ; pyro-phosphorus acid, $\text{H}_4\text{P}_2\text{O}_5$; ortho-phosphorus acid, H_3PO_3 ; hypo-phosphoric acid, $\text{H}_4\text{P}_2\text{O}_6$; meta-phosphoric acid, HPO_3 ; pyro-phosphoric acid, $\text{H}_4\text{P}_2\text{O}_7$; and orthophosphoric acid, H_3PO_4 . As an example, the formation of ortho-phosphoric, H_3PO_4 , due to reverse hydrolysis by residual or ambient moisture, is:

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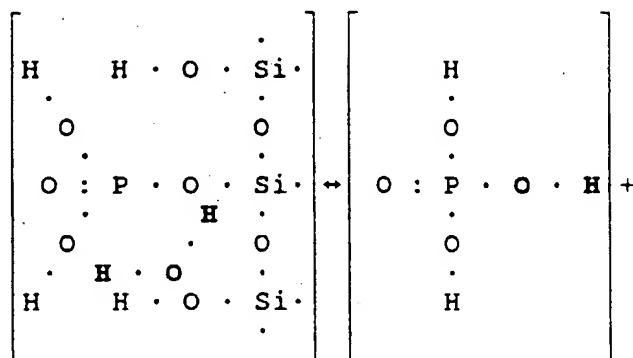
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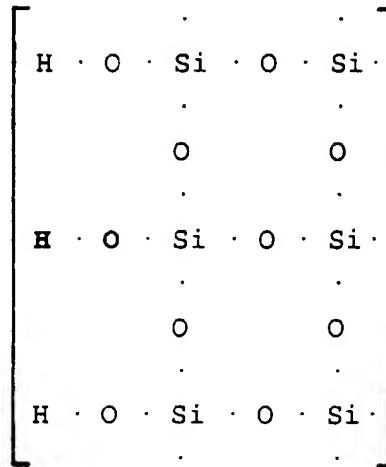
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The acids that are formed corrode aluminum interconnects. Consequently, for planarization over aluminum interconnects, when maximum temperature is limited to about 450°C or so, serious problems are encountered with film quality and reliability.

These effects are not observed in the planarization of dielectrics over refractory materials, such as polysilicon, silicides and refractory metals, that allow very high temperature curing (over 800°C) due to more complete thermally induced condensation of pairs of silanol bonds, Si-OH, over long distances. This type of planarization over refractory materials is relatively easy.

The difficulty of using silicate SOGs for the planarization of low-melting point materials such as aluminum has caused a worldwide trend not to use purely inorganic silicate (including phosphosilicate) SOGs and to use instead members of the quasi-inorganic siloxane family.

One example of the use of such a technique is described in the Journal of the Electrochemical Society, vol. 135, no. 5, May 1988, pages 1207-1210. This article describes the use of a commercially available polysiloxane film having the formula $\text{R}_3\text{Si-O-(SiR}_2\text{-O)}_n\text{-SiR}_3$; where $\text{R} = \text{CH}_3, \text{C}_2\text{H}_5$ etc. to planarize wafers with aluminum interconnect tracks. As can be seen, this spin-on glass includes the alkyl group R, which gives the film some organic properties, thus classifying it as "quasi-organic" spin-on glass in contrast to a purely inorganic silicate glass. Unlike purely inorganic SOGs, which consist of silicate glasses that are inherently brittle, quasi-inorganic SOGs have a greater flexibility due to the carbon content. Quasi-inorganic SOGs are thus easier to work with because their inherent flexibility makes them more tolerant to shrinkage.

The article "Defects Study on Spin-on Glass Planarization Technology", Proceedings of the Fourth International IEEE VLSI Multilevel Interconnection Conference, June 15-16, 1987, pages 404 - 412, discusses the use of SOG as a planarization material. While this article recognizes the disadvantage of having moisture present in a formed spin-on glass layer in terms of the effect the moisture has on the overlying layers, the article deals with organic SOGs and is silent as to the desirability of eliminating moisture during the planarization process.

However, there are significant disadvantages in using quasi-inorganic SOGs relating to their electrical properties, and their use is becoming uncertain for advanced applications. A further problem is caused by the absorption of water during curing. SOGs, particularly phosphorus alloyed SOGs, are extremely hygroscopic materials, and rapidly absorb ambient moisture during curing. This moisture pick-up promotes the irreversible reactions described above, and the resulting SOG films have poor properties and reliability.

An object of the invention is to alleviate the afore-mentioned problems by permitting the obtention of higher quality SOG films, mainly inorganic SOG films, over aluminum or other materials that cannot tolerate high temperature processing.

According to the present invention there is provided a method of planarizing a semiconductor wafer having non-refractory material thereon, comprising applying a spin-on glass to said wafer, characterized in that said spin-on glass is an inorganic spin-on glass which is applied in the following manner:

- (i) the spin-on glass is applied to the wafer in a coating and spinning zone in a moisture-free environment;
- (ii) the wafer is transferred in a moisture-free environment to a curing zone;
- (iii) the spin-on glass is cured still in a moisture-free environment; and

(iv) steps (i) to (iii) are repeated until a sufficient film thickness has been achieved whilst maintaining the wafer at all times in a moisture-free environment, thus forming said spin-on glass on said wafer without permitting the wafer to absorb moisture so as to minimize reverse hydrolysis during the planarization process.

5 In one embodiment, the non-refractory material is aluminium.

By eliminating the moisture from the curing process, a dense, low hydrogen content, high coefficient of thermal expansion, flexible, crack-resistant and corrosion-free SOG film can be produced.

10 After deposition of the first layer of dielectric, the spin-on glass coating/cure process is preferably carried out with a dedicated SOG processor, typically in the following manner, which is described with reference to the planarization of a series of semiconductor wafers:

- a) The wafer is transported from sending cassette to a coating chamber.
- b) A few ml of a SOG solution are dispensed at the centre of the wafer to be planarized.
- c) The wafer is spun at a given RPM to spread uniformly the solution and to permit the evaporation of volatile compounds and film solidification.
- 15 d) For SOG curing, the wafer is sequentially transported to in-line hot plates which are temperature controlled at temperature roughly between 80°C and 250°C.
- e) The wafer is slightly cooled at an idle station.
- f) The wafer is stored and cooled in a receiving cassette.
- 20 g) When all the wafers are received in the receiving cassette, they are all together transferred to the sending cassette for a second coat (steps a to f are repeated). When all the wafers are received in receiving cassette, they are all together transferred to the sending cassette for a third coat (steps a to f are again repeated).
- h) When sufficient coats have been applied, the wafers are transferred to the station for the next process step.

25 During steps a) to g), an operation lasting about two hours, the wafers are not exposed to ambient atmosphere and, unlike the prior art, are maintained in a moisture-free environment. As a result, the SOG films, particularly phosphorus alloyed SOG films, cannot therefore absorb ambient moisture and extremely high quality films are produced.

The invention will now be described in more detail, by way of example only, with reference to the accompanying drawings in which:-

30 Figures 1a and 1b show respectively plan and side views of a SOG planarization apparatus for carrying out the process according to the present invention; and

35 Figure 2 is a plot of the stress in a SOG film plotted against relative humidity.

SOG processing equipment for coating and in-line curing of the SOG film is relatively new. Prior art SOG processors do not allow wafer manipulations, SOG coating, in-line curing, cooling and storage under continuously controlled ambient stations.

40 These in-line ambient controlled stations are provided in the SOG processor shown in Figure 1. Referring now to Figure 1, the SOG processor comprises a main unit 1 defining a plurality of processing stations. The unit includes sending cassettes 4, transport mechanisms 2, in-line cure plates 6a, 6b, 6c, and receiving cassettes 7. The unit 1 further has a coating area 5 and cooling area 3.

More particularly, the SOG processor comprises the following elements:

- 45 1) One or more sending cassettes 4 to store the wafers to be processed.
- 2) Transport mechanism 2 to transfer, one by one, the wafers from the sending cassette to the coating area.
- 3) Coating area 5 where the SOG coating and wafer spinning is done.
- 4) Transport mechanism 2 to transfer the coated wafer from the coating area to the first in-line temperature controlled hot plate.
- 50 5) A first in-line hot plate area 6a.
- 6) Transport mechanism 2 to transfer the wafer from the one in-line hot plate to the next.
- 7) A last in-line hot plate area 6c.
- 8) A transport mechanism to transfer the wafer from the last in-line hot plate to a wafer cooling area.
- 9) A wafer cooling area 7.
- 55 10) A transport mechanism to transfer the wafer from the wafer cooling area to a receiving cassette area.
- 11) One or more receiving cassettes 7 to store the wafers that have received the first SOG coat.

The entire processor is provided in an inert environment.

The inert gas ambient protects the wafer at locations 1 to 7. The inert gas is typically nitrogen, but can be argon or any other noble gas or any other non-reactive moisture-free gas. This gas prevents reverse hydrolysis and permits the production of films with considerably improved properties. In order to determine the effects of moisture on film properties, various SOG films were prepared using the apparatus shown in Figure 1. The results are shown in Figure 2. Film stress was monitored for films processed under uncontrolled atmospheric ambient and correlated with relative humidity to show its effect on film properties. Moisture pick-up and reverse hydrolysis pushes SOG film stress toward compression (less tensile) because of an internal volumetric expansion due to the formation of silanol, Si-OH, pairs from more compact Si-O-Si bonds.

The water pick-up effect is shown in Figure 2, which shows that the equilibrium SOG mechanical stress is mainly controlled by relative humidity. The compressive stress effect due to the formation of silanol pairs is effectively observed; the higher the relative humidity, the lower the tensile stress.

Since the ambient conditions such as dew point, relative humidity, and duration of the ambient exposure are not constant from wafer to wafer and day to day, the resulting films properties fluctuate and manufacturing is difficult.

While the invention is mainly applicable to inorganic SOGs, it can be applied with success to quasi-inorganic SOGs. Either type can be alloyed or not with phosphorus, boron, arsenic or lead. The benefits of the invention are more noticeable with alloyed SOGs, but, since a non-alloyed SOG is also extremely hygroscopic, the technique also apply to unalloyed SOGs.

The number of coats can vary. Generally speaking, the higher the number of coats, the better the end results.

The in-line high temperature hot plates can be replaced by an in-line oven, an in-line plasma cure device, an in-line microwave device, or an in-line ozone device, or an in-line UV-ozone device, to permit cure in a moisture-free gas.

This inert gas is typically nitrogen, but it can be argon or another noble gas, any other moisture-free gas, a mixture thereof. It can be heated or at room temperature.

The inert gas ambient can also be replaced by a vacuum, which is also a moisture-free environment. The gas can be ionized (plasma) or not.

Claims

1. A method of planarizing a semiconductor wafer having non-refractory material thereon, comprising applying a spin-on glass to said wafer, characterized in that said spin-on glass is an inorganic spin-on glass which is applied in the following manner:

- (i) the spin-on glass is applied to the wafer in a coating and spinning zone in a moisture-free environment;
- (ii) the wafer is transferred in a moisture-free environment to a curing zone;
- (iii) the spin-on glass is cured still in a moisture-free environment; and
- (iv) steps (i) to (iii) are repeated until a sufficient film thickness has been achieved whilst maintaining the wafer at all times in a moisture-free environment, thus forming said spin-on glass on said wafer without permitting the wafer to absorb moisture so as to minimize reverse hydrolysis during the planarization process.

2. A method as claimed in claim 1, characterized in that said moisture-free environment comprises an inert gas.

3. A method as claimed in claim 2, characterized in that said inert gas is selected from the group consisting of: nitrogen, argon or other noble gas.

4. A method as claimed in claim 1, characterized in that said moisture-free environment comprises a vacuum.

5. A method as claimed in claim 1, characterized in that said spin-on glass is a phosphorus-alloyed spin-on glass.

6. A method as claimed in claim 5, characterized in that said spin-on glass is applied wholly within said moisture-free environment and without exposing the wafer to ambient conditions in the interim as follows:

- 1) the wafer to be processed is placed in a sending cassette;
- 2) the wafer is transferred from said sending cassette to the coating and spinning zone;
- 3) a few ml of inorganic spin-on glass are dispensed at the centre of the wafer, and said wafer is spun;
- 4) the coated wafer is transferred from the coating and spinning zone to a first in-line temperature controlled hot plate;
- 5) the wafer is transferred from the said first in-line hot plate to the next and so on to the last in-line hot plate;
- 6) the wafer is transferred from the last in-line hot plate to a wafer cooling zone;

- 7) the wafer is transferred from the wafer cooling zone to a receiving cassette zone;
- 8) the wafer is stored in a receiving cassette; and
- 9) steps 1 to 8 are repeated as many times as required until a sufficient film thickness has been achieved.

5 7. A method as claimed in any one of claims 1 to 6, characterized in that said non-refractory material is aluminum.

Patentansprüche

- 10 1. Verfahren zur Planarisierung eines Halbleiterplättchens überzogen mit schmelzbarem Material, daß die Beschichtung des o.g. Halbleiterplättchens mit Glas durch ein Schleudergußverfahren umfaßt, dadurch gekennzeichnet, daß das o.g. Schleuderguß-Glas ein anorganisches Schleudergußglas ist, das wie folgt aufgetragen wird:
 - 15 (i) das Schleuderguß-Glas wird auf das Halbleiterplättchen in einer Beschichtungs- und Schleudergußzone in einer feuchtigkeitsfreien Umgebung aufgetragen;
 - (ii) das Halbleiterplättchen wird in einer feuchtigkeitsfreien Umgebung zu einer Härtingszone transportiert;
 - (iii) das Schleuderguß-Glas wird still in einer feuchtigkeitsfreien Umgebung ausgehärtet; und
 - (iv) die Schritte (i) bis (iii) werden wiederholt, bis eine ausreichende Schichtstärke erreicht wird, wobei die Halbleiterplättchen jederzeit in einer feuchtigkeitsfreien Umgebung gehalten und das Schleuderguß-Glas dabei auf dem o.g. Halbleiterplättchen geformt wird, ohne zuzulassen, daß das Halbleiterplättchen Feuchtigkeit absorbiert, um damit die Rückhydrolyse während des Planarisierungsprozesses zu minimalisieren.
- 20 2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die o.g. feuchtigkeitsfreie Umgebung aus einem inerten Gas besteht.
- 25 3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß das o.g. inerte Gas aus einer Gruppe ausgewählt wird, die aus den folgenden Gasen besteht: Stickstoff, Argon oder ein anderes Edelgas.
- 30 4. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die o.g. feuchtigkeitsfreie Umgebung aus einem Vakuum besteht.
5. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das o.g. Schleuderguß-Glas ein phosphorlegiertes Schleuderguß-Glas ist.
- 35 6. Verfahren nach Anspruch 5, dadurch gekennzeichnet, daß das o.g. Schleuderguß-Glas ausschließlich in der vorerwähnten feuchtigkeitsfreien Umgebung aufgetragen wird und ohne daß das Halbleiterplättchen dabei den Umgebungsverhältnissen wie folgt nicht ausgesetzt wird:
 - 40 1) das zu bearbeitende Halbleiterplättchen wird in eine Sendekassette gesetzt;
 - 2) das Halbleiterplättchen wird von der o.g. Aufnahmekassette zur Beschichtungs- und Schleuderzone übergeführt;
 - 3) einige ml anorganisches Schleuderguß-Glas werden in der Mitte des Halbleiterplättchens verstreut und das vorerwähnte Halbleiterplättchen gedreht;
 - 4) das beschichtete Halbleiterplättchen wird von der Beschichtungs- und Schleuderzone in die erste aufeinanderfolgende heiße Platte mit Temperaturregelung übergeführt;
 - 45 5) das Halbleiterplättchen wird von der o.g. ersten in einer Reihe liegenden heißen Platte zur nächsten Platte, und so weiter bis zur letzten heißen Platte in dieser Reihe übergeführt;
 - 6) das Halbleiterplättchen wird von der letzten heißen Platte in der Reihe zur Abkühlungszone für Halbleiterplättchen übergeführt;
 - 50 7) das Halbleiterplättchen wird von der Abkühlungszone zu einer Aufnahmekassette-Zone übergeführt;
 - 8) das Halbleiterplättchen wird in einer Aufnahmekassette aufbewahrt; und
 - 9) die Schritte 1 bis 8 werden so lange wiederholt, bis eine ausreichende Schichtstärke erreicht wird.
- 55 7. Verfahren nach einem der Ansprüche 1 bis 6, dadurch gekennzeichnet, daß das o.g. schmelzbare Material Aluminium ist.

Revendications

1. Un procédé planar qui s'applique à une plaquette semiconductrice enrobée d'une matière non réfractaire, consistant à appliquer un verre rotatif à ladite plaquette, caractérisée en ce que ledit verre rotatif est un verre rotatif inorganique qui est appliqué de la façon suivante :

- i) le verre rotatif est appliqué à la plaquette dans une zone d'enrobage et de rotation dans un milieu sec;
- ii) la plaquette est transférée dans un milieu sec à une zone de vulcanisation;
- iii) le verre rotatif est vulcanisé, immobile, dans un milieu sec; et
- iv) on répète les étapes i) à iii) jusqu'à ce qu'une épaisseur de film suffisante ait été atteinte, en maintenant la plaquette constamment dans un milieu sec, moulant ainsi le verre rotatif sur ladite plaquette - sans permettre à la plaquette d'absorber l'humidité afin de minimiser l'hydrolyse inverse pendant le procédé planar.

2. Un procédé selon la revendication 1, caractérisé en ce que ledit milieu sec comprend un gaz inerte.

3. Un procédé selon la revendication 2, caractérisé en ce que ledit gaz inerte est choisi dans le groupe consistant en azote, argon ou autre gaz rare.

4. Un procédé selon la revendication 1, caractérisé en ce que ledit milieu sec comprend un vide.

5. Un procédé selon la revendication 1, caractérisé en ce que ledit verre rotatif est un verre rotatif en alliage de phosphore.

6. Un procédé selon la revendication 5, caractérisé en ce que ledit verre rotatif est appliqué entièrement à l'intérieur dudit milieu sec et sans exposer la plaquette aux conditions ambiantes provisoirement, de la façon suivante :

- 1) la plaquette devant être traitée est placée dans une cassette d'émission;
- 2) la plaquette est transférée de ladite cassette à la zone d'enrobage et de rotation;
- 3) quelques millilitres de verre rotatif inorganique sont placés au centre de la plaquette, et ladite plaquette tourne;
- 4) la plaquette enrobée est transférée de la zone d'enrobage et de rotation à une première plaque chauffante dans la rangée dont la température est contrôlée;
- 5) la plaquette est transférée de ladite première plaque chauffante à la suivante et ainsi de suite jusqu'à la dernière plaque chauffante dans la rangée;
- 6) la plaquette est transférée de la dernière plaquette chauffante dans la rangée à une zone de refroidissement des plaquettes;
- 7) la plaquette est transférée de la zone de refroidissement des plaquettes à une zone de cassette de réception;
- 8) la plaquette est entreposée dans une cassette de réception; et
- 9) les étapes 1 à 8 sont répétées aussi souvent que nécessaire jusqu'à l'obtention d'une épaisseur suffisante.

7. Un procédé selon n'importe laquelle des revendications 1 à 6, caractérisées en ce que le matériel non réfractaire est l'aluminium.

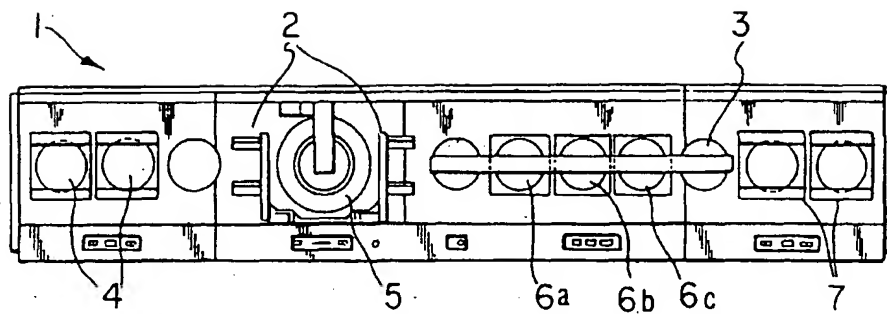


FIG. 1a

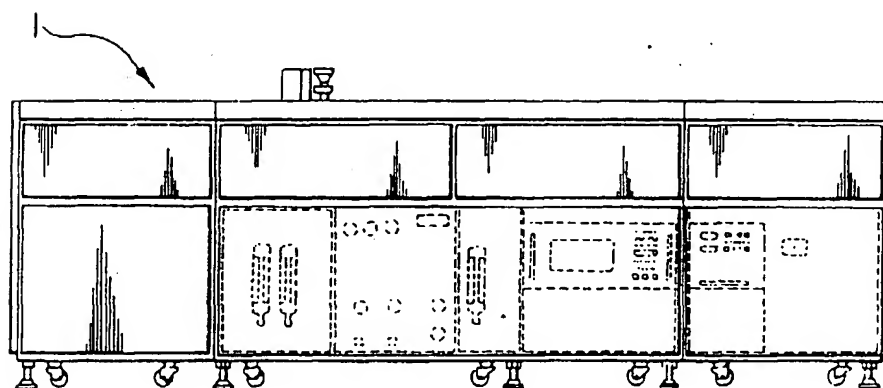


FIG. 1b

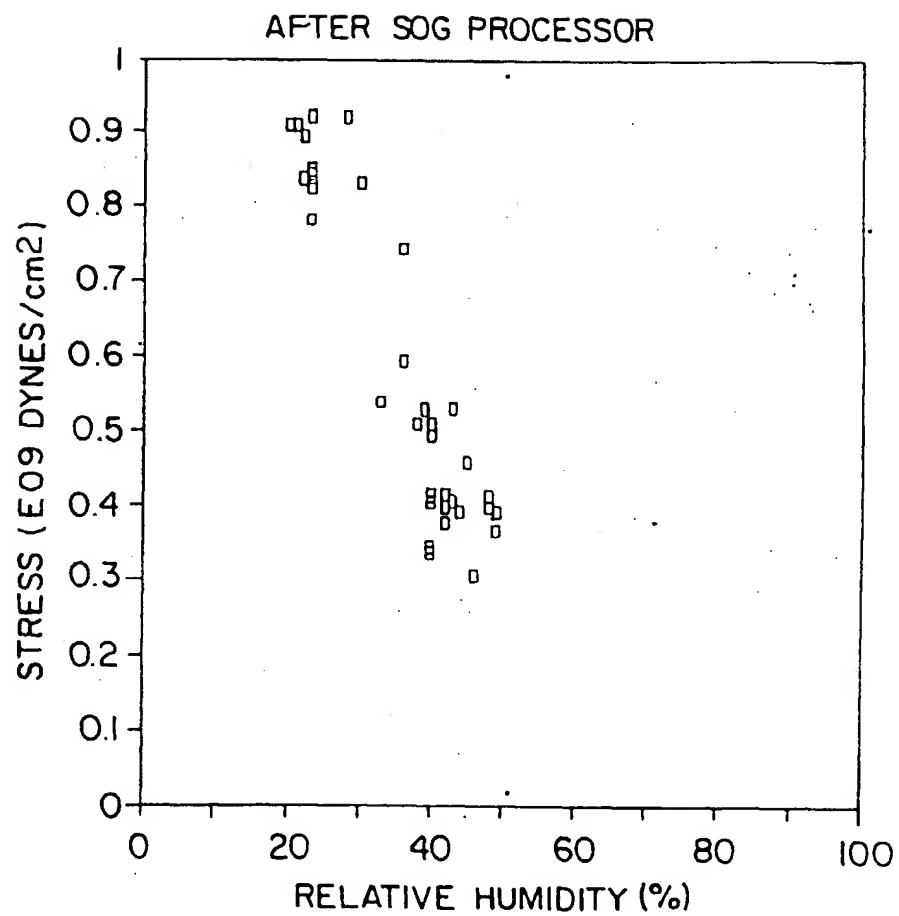


FIG.2

(iv) steps (i) to (iii) are repeated until a sufficient film thickness has been achieved whilst maintaining the wafer at all times in a moisture-free environment, thus forming said spin-on glass on said wafer without permitting the wafer to absorb moisture so as to minimize reverse hydrolysis during the planarization process.

5 In one embodiment, the non-refractory material is aluminium.

By eliminating the moisture from the curing process, a dense, low hydrogen content, high coefficient of thermal expansion, flexible, crack-resistant and corrosion-free SOG film can be produced.

After deposition of the first layer of dielectric, the spin-on glass coating/cure process is preferably carried out with a dedicated SOG processor, typically in the following manner, which is described with reference to the planarization
10 of a series of semiconductor wafers:

- a) The wafer is transported from sending cassette to a coating chamber.
- b) A few ml of a SOG solution are dispensed at the centre of the wafer to be planarized.
- c) The wafer is spun at a given RPM to spread uniformly the solution and to permit the evaporation of volatile
15 compounds and film solidification.
- d) For SOG curing, the wafer is sequentially transported to in-line hot plates which are temperature controlled at temperature roughly between 80°C and 250°C.
- e) The wafer is slightly cooled at an idle station.
- f) The wafer is stored and cooled in a receiving cassette.
- 20 g) When all the wafers are received in the receiving cassette, they are all together transferred to the sending cassette for a second coat (steps a to f are repeated). When all the wafers are received in receiving cassette, they are all together transferred to the sending cassette for a third coat (steps a to f are again repeated).
- h) When sufficient coats have been applied, the wafers are transferred to the station for the next process step.

25 During steps a) to g), an operation lasting about two hours, the wafers are not exposed to ambient atmosphere and, unlike the prior art, are maintained in a moisture-free environment. As a result, the SOG films, particularly phosphorus alloyed SOG films, cannot therefore absorb ambient moisture and extremely high quality films are produced.

The invention will now be described in more detail, by way of example only, with reference to the accompanying
30 drawings in which:-

Figures 1a and 1b show respectively plan and side views of a SOG planarization apparatus for carrying out the process according to the present invention; and

35 Figure 2 is a plot of the stress in a SOG film plotted against relative humidity.

SOG processing equipment for coating and in-line curing of the SOG film is relatively new. Prior art SOG processors do not allow wafer manipulations, SOG coating, in-line curing, cooling and storage under continuously controlled ambient stations.

These in-line ambient controlled stations are provided in the SOG processor shown in Figure 1. Referring now to
40 Figure 1, the SOG processor comprises a main unit 1 defining a plurality of processing stations. The unit includes sending cassettes 4, transport mechanisms 2, in-line cure plates 6a, 6b, 6c, and receiving cassettes 7. The unit 1 further has a coating area 5 and cooling area 3.

More particularly, the SOG processor comprises the following elements:

- 45 1) One or more sending cassettes 4 to store the wafers to be processed.
- 2) Transport mechanism 2 to transfer, one by one, the wafers from the sending cassette to the coating area.
- 3) Coating area 5 where the SOG coating and wafer spinning is done.
- 4) Transport mechanism 2 to transfer the coated wafer from the coating area to the first in-line temperature controlled hot plate.
- 50 5) A first in-line hot plate area 6a.
- 6) Transport mechanism 2 to transfer the wafer from the one in-line hot plate to the next.
- 7) A last in-line hot plate area 6c.
- 8) A transport mechanism to transfer the wafer from the last in-line hot plate to a wafer cooling area.
- 9) A wafer cooling area 7.
- 55 10) A transport mechanism to transfer the wafer from the wafer cooling area to a receiving cassette area.
- 11) One or more receiving cassettes 7 to store the wafers that have received the first SOG coat.

The entire processor is provided in an inert environment.

The inert gas ambient protects the wafer at locations 1 to 7. The inert gas is typically nitrogen, but can be argon or any other noble gas or any other non-reactive moisture-free gas. This gas prevents reverse hydrolysis and permits the production of films with considerably improved properties. In order to determine the effects of moisture on film properties, various SOG films were prepared using the apparatus shown in Figure 1. The results are shown in Figure 2. Film stress was monitored for films processed under uncontrolled atmospheric ambient and correlated with relative humidity to show its effect on film properties. Moisture pick-up and reverse hydrolysis pushes SOG film stress toward compression (less tensile) because of an internal volumetric expansion due to the formation of silanol, Si-OH, pairs from more compact Si-O-Si bonds.

The water pick-up effect is shown in Figure 2, which shows that the equilibrium SOG mechanical stress is mainly controlled by relative humidity. The compressive stress effect due to the formation of silanol pairs is effectively observed; the higher the relative humidity, the lower the tensile stress.

Since the ambient conditions such as dew point, relative humidity, and duration of the ambient exposure are not constant from wafer to wafer and day to day, the resulting films properties fluctuate and manufacturing is difficult.

While the invention is mainly applicable to inorganic SOGs, it can be applied with success to quasi-inorganic SOGs. Either type can be alloyed or not with phosphorus, boron, arsenic or lead. The benefits of the invention are more noticeable with alloyed SOGs, but, since a non-alloyed SOG is also extremely hygroscopic, the technique also apply, to unalloyed SOGs.

The number of coats can vary. Generally speaking, the higher the number of coats, the better the end results.

The in-line high temperature hot plates can be replaced by an in-line oven, an in-line plasma cure device, an in-line microwave device, or an in-line ozone device, or an in-line UV-ozone device, to permit cure in a moisture-free gas.

This inert gas is typically nitrogen, but it can be argon or another noble gas, any other moisture-free gas, a mixture thereof. It can be heated or at room temperature.

The inert gas ambient can also be replaced by a vacuum, which is also a moisture-free environment. The gas can be ionized (plasma) or not.

Claims

1. A method of planarizing a semiconductor wafer having non-refractory material thereon, comprising applying a spin-on glass to said wafer, characterized in that said spin-on glass is an inorganic spin-on glass which is applied in the following manner:

- (i) the spin-on glass is applied to the wafer in a coating and spinning zone in a moisture-free environment;
- (ii) the wafer is transferred in a moisture-free environment to a curing zone;
- (iii) the spin-on glass is cured still in a moisture-free environment; and
- (iv) steps (i) to (iii) are repeated until a sufficient film thickness has been achieved whilst maintaining the wafer at all times in a moisture-free environment, thus forming said spin-on glass on said wafer without permitting the wafer to absorb moisture so as to minimize reverse hydrolysis during the planarization process.

2. A method as claimed in claim 1, characterized in that said moisture-free environment comprises an inert gas.

3. A method as claimed in claim 2, characterized in that said inert gas is selected from the group consisting of: nitrogen, argon or other noble gas.

4. A method as claimed in claim 1, characterized in that said moisture-free environment comprises a vacuum.

5. A method as claimed in claim 1, characterized in that said spin-on glass is a phosphorus-alloyed spin-on glass.

6. A method as claimed in claim 5, characterized in that said spin-on glass is applied wholly within said moisture-free environment and without exposing the wafer to ambient conditions in the interim as follows:

- 1) the wafer to be processed is placed in a sending cassette;
- 2) the wafer is transferred from said sending cassette to the coating and spinning zone;
- 3) a few ml of inorganic spin-on glass are dispensed at the centre of the wafer, and said wafer is spun;
- 4) the coated wafer is transferred from the coating and spinning zone to a first in-line temperature controlled hot plate;
- 5) the wafer is transferred from the said first in-line hot plate to the next and so on to the last in-line hot plate;
- 6) the wafer is transferred from the last in-line hot plate to a wafer cooling zone;

- 7) the wafer is transferred from the wafer cooling zone to a receiving cassette zone;
- 8) the wafer is stored in a receiving cassette; and
- 9) steps 1 to 8 are repeated as many times as required until a sufficient film thickness has been achieved.

5 7. A method as claimed in any one of claims 1 to 6, characterized in that said non-refractory material is aluminum.

Patentansprüche

- 10 1. Verfahren zur Planarisierung eines Halbleiterplättchens überzogen mit schmelzbarem Material, daß die Beschichtung des o.g. Halbleiterplättchens mit Glas durch ein Schleudergußverfahren umfaßt, dadurch gekennzeichnet, daß das o.g. Schleuderguß-Glas ein anorganisches Schleudergußglas ist, das wie folgt aufgetragen wird:
 - 15 (i) das Schleuderguß-Glas wird auf das Halbleiterplättchen in einer Beschichtungs- und Schleudergußzone in einer feuchtigkeitsfreien Umgebung aufgetragen;
 - (ii) das Halbleiterplättchen wird in einer feuchtigkeitsfreien Umgebung zu einer Härtingszone transportiert;
 - (iii) das Schleuderguß-Glas wird still in einer feuchtigkeitsfreien Umgebung ausgehärtet; und
 - (iv) die Schritte (i) bis (iii) werden wiederholt, bis eine ausreichende Schichtstärke erreicht wird, wobei die Halbleiterplättchen jederzeit in einer feuchtigkeitsfreien Umgebung gehalten und das Schleuderguß-Glas dabei auf dem o.g. Halbleiterplättchen geformt wird, ohne zuzulassen, daß das Halbleiterplättchen Feuchtigkeit absorbiert, um damit die Rückhydrolyse während des Planarisierungsprozesses zu minimalisieren.
- 20 2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die o.g. feuchtigkeitsfreie Umgebung aus einem inerten Gas besteht.
- 25 3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß das o.g. inerte Gas aus einer Gruppe ausgewählt wird, die aus den folgenden Gasen besteht: Stickstoff, Argon oder ein anderes Edelgas.
- 30 4. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die o.g. feuchtigkeitsfreie Umgebung aus einem Vakuum besteht.
5. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das o.g. Schleuderguß-Glas ein phosphorlegiertes Schleuderguß-Glas ist.
- 35 6. Verfahren nach Anspruch 5, dadurch gekennzeichnet, daß das o.g. Schleuderguß-Glas ausschließlich in der vorerwähnten feuchtigkeitsfreien Umgebung aufgetragen wird und ohne daß das Halbleiterplättchen dabei den Umgebungsverhältnissen wie folgt nicht ausgesetzt wird:
 - 40 1) das zu bearbeitende Halbleiterplättchen wird in eine Sendekassette gesetzt;
 - 2) das Halbleiterplättchen wird von der o.g. Aufnahmekassette zur Beschichtungs- und Schleuderzone übergeführt;
 - 3) einige ml anorganisches Schleuderguß-Glas werden in der Mitte des Halbleiterplättchens verstreut und das vorerwähnte Halbleiterplättchen gedreht;
 - 4) das beschichtete Halbleiterplättchen wird von der Beschichtungs- und Schleuderzone in die erste aufeinanderfolgende heiße Platte mit Temperaturregelung übergeführt;
 - 45 5) das Halbleiterplättchen wird von der o.g. ersten in einer Reihe liegenden heißen Platte zur nächsten Platte, und so weiter bis zur letzten heißen Platte in dieser Reihe übergeführt;
 - 6) das Halbleiterplättchen wird von der letzten heißen Platte in der Reihe zur Abkühlungszone für Halbleiterplättchen übergeführt;
 - 50 7) das Halbleiterplättchen wird von der Abkühlungszone zu einer Aufnahmekassette-Zone übergeführt;
 - 8) das Halbleiterplättchen wird in einer Aufnahmekassette aufbewahrt; und
 - 9) die Schritte 1 bis 8 werden so lange wiederholt, bis eine ausreichende Schichtstärke erreicht wird.
- 55 7. Verfahren nach einem der Ansprüche 1 bis 6, dadurch gekennzeichnet, daß das o.g. schmelzbare Material Aluminium ist.

Revendications

1. Un procédé planar qui s'applique à une plaquette semiconductrice enrobée d'une matière non réfractaire, consistant à appliquer un verre rotatif à ladite plaquette, caractérisée en ce que ledit verre rotatif est un verre rotatif inorganique qui est appliqué de la façon suivante :

- i) le verre rotatif est appliqué à la plaquette dans une zone d'enrobage et de rotation dans un milieu sec;
- (ii) la plaquette est transférée dans un milieu sec à une zone de vulcanisation;
- (iii) le verre rotatif est vulcanisé, immobile, dans un milieu sec; et
- (iv) on répète les étapes i) à iii) jusqu'à ce qu'une épaisseur de film suffisante ait été atteinte, en maintenant la plaquette constamment dans un milieu sec, moulant ainsi le verre rotatif sur ladite plaquette - sans permettre à la plaquette d'absorber l'humidité afin de minimiser l'hydrolyse inverse pendant le procédé planar.

2. Un procédé selon la revendication 1, caractérisé en ce que ledit milieu sec comprend un gaz inerte.

3. Un procédé selon la revendication 2, caractérisé en ce que ledit gaz inerte est choisi dans le groupe consistant en azote, argon ou autre gaz rare.

4. Un procédé selon la revendication 1, caractérisé en ce que ledit milieu sec comprend un vide.

5. Un procédé selon la revendication 1, caractérisé en ce que ledit verre rotatif est un verre rotatif en alliage de phosphore.

6. Un procédé selon la revendication 5, caractérisé en ce que ledit verre rotatif est appliqué entièrement à l'intérieur dudit milieu sec et sans exposer la plaquette aux conditions ambiantes provisoirement, de la façon suivante :

- 1) la plaquette devant être traitée est placée dans une cassette d'émission;
- 2) la plaquette est transférée de ladite cassette à la zone d'enrobage et de rotation;
- 3) quelques millilitres de verre rotatif inorganique sont placés au centre de la plaquette, et ladite plaquette tourne;
- 4) la plaquette enrobée est transférée de la zone d'enrobage et de rotation à une première plaque chauffante dans la rangée dont la température est contrôlée;
- 5) la plaquette est transférée de ladite première plaque chauffante à la suivante et ainsi de suite jusqu'à la dernière plaque chauffante dans la rangée;
- 6) la plaquette est transférée de la dernière plaquette chauffante dans la rangée à une zone de refroidissement des plaquettes;
- 7) la plaquette est transférée de la zone de refroidissement des plaquettes à une zone de cassette de réception;
- 8) la plaquette est entreposée dans une cassette de réception; et
- 9) les étapes 1 à 8 sont répétées aussi souvent que nécessaire jusqu'à l'obtention d'une épaisseur suffisante.

7. Un procédé selon n'importe laquelle des revendications 1 à 6, caractérisées en ce que le matériel non réfractaire est l'aluminium.

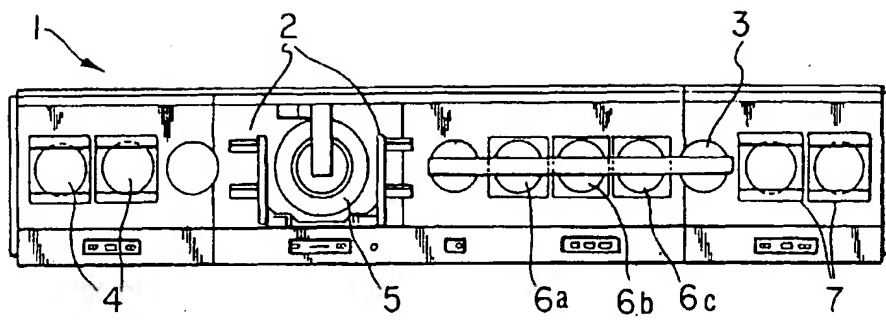


FIG. 1a

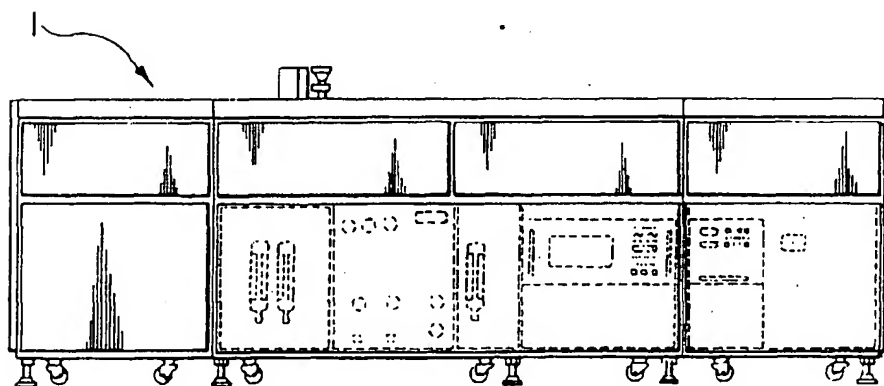


FIG. 1b

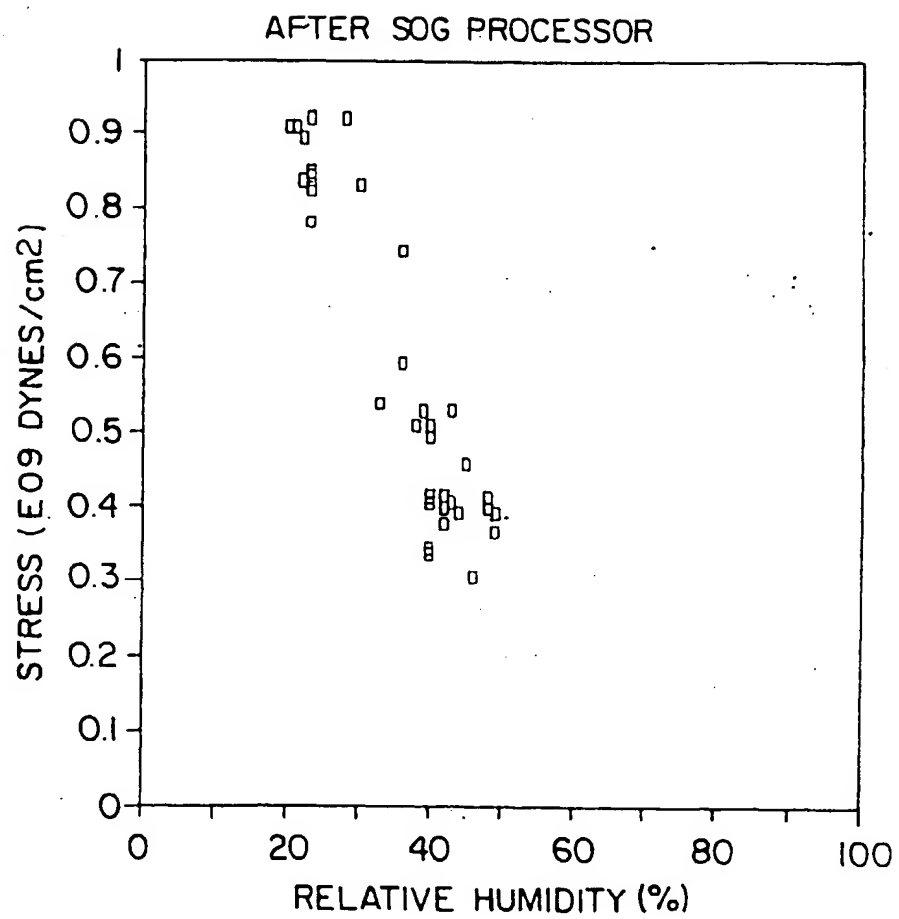


FIG. 2